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Research on the social perception of invasive species: a systematic literature review

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Abstract

We conducted a systematic literature review of the current state of research on the social perceptions of invasive species, aiming to provide guidance towards transdisciplinary research and participatory decision making. In order to detect patterns regarding publication trends and factors determining social perceptions of invasive species, we applied qualitative content as well as quantitative data analysis. By applying content analysis, we identified five main categories of influence on the perception of invasive species: ecological conditions, social conditions, values and beliefs, impacts, and benefits. The disciplinary focus of the research was predominantly interdisciplinary, followed by a social sciences approach. Our review revealed a disproportionate use of quantitative methods in research on social perceptions of invasive species, yet quantitative methods were less likely to identify benefits as factors determining the perception of invasive species. However, without the understanding of perceived benefits, researchers and managers lack the socio-cultural context these species are embedded in. Our review also revealed the geographical, methodological and taxonomic bias of research on perceptions of invasive species. The majority of studies focused on the local public, whereas fewer than half of the studies focused on decision-makers. Furthermore, our results showed differences in the social perceptions of invasive species among different stakeholder groups. Consensus over the definition and terminology of invasive species was lacking whereas differences in terminology were clearly value-laden. In order to foster sustainable management of invasive species, research on social perceptions should focus on a transdisciplinary and transparent discourse about the inherent values of invasion science.

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Keywords
conservation management, disciplinary bias, human perception, introduced species, stakeholders, transdisciplinary research

Introduction

Ecological research has been investigating the phenomenon of invasive alien species increasingly since the midst of the 20th century. Early research mainly focused on ecological aspects of biological invasions like principles of the invasion process (Sakai et al. 2001; Keane and Crawley 2002; Pyšek et al. 2008, Vaz et al. 2017a) and invasive species impacts on ecosystems (Parker et al. 1999; Ehrenfeld 2003; Gurevitch and Padilla 2004; Stricker et al. 2015). The economic costs incurred by biological invasions have gained more attention in recent studies (van Wilgen et al. 2001; Pimentel et al. 2005; Brunson and Tanaka 2011). However, the lack of social and cultural perspectives on invasive species has been repeatedly criticized (Gobster 2005, 2011; Gozlan et al. 2013; Abrahams et al. 2019). The exclusion of public perceptions from science and conservation management research creates a gap between the dynamics of invasions' processes and stakeholders' interests. First, since perceptions of invasive species are diverse (García-Llorente et al. 2008), opposing attitudes towards invasive species can only be understood by implementing social perspectives in research and decision-making. While decision-makers and scientists may hold more extreme views in relation to species' nativeness and abundance (Fischer et al. 2014), rural communities in South Africa, for example, perceived higher densities of an invasive cactus species as positive. This was on account of the usage of its fruits that provide notable socio-economic value (Shackleton et al. 2007). Second, the public may refuse to engage in, and even oppose, management measures concerning invasive species if their perspectives are ignored or misunderstood (Simberloff 2011; Woodford et al. 2016). To this end, Rotherham and Lambert (2011) show that county bird recorders in the UK simply withhold the location details of invasive ruddy duck breeding and wintering sites to save them from culling. Moreover, opposition from the public can result in conflicts with far-reaching consequences (Keulartz and van der Weele 2009), as in California, USA, where the eradication program targeting a pike species widely ignored stakeholders from the public, triggering lawsuits against the responsible authorities (Lee 2001). The examples imply that the integration and understanding of social and cultural perspectives in research on invasive species, and the consideration of biological invasions as social-ecological phenomena, is crucial for their sustainable, i.e. both ecologically and socially successful, management (Kueffer 2013).

Recently, research on biological invasions has recognized the importance of social perceptions of alien invasive species for their management (Kueffer 2017, Shackleton et al. 2019a) with some rare exceptions focusing on human dimensions of biological invasions earlier (e.g. McNeely 2001; McNeely 2005). Research on social perceptions of invasive species is rather broad and has considered different aspects, such as stakeholders' knowledge concerning invasive species (Eiswerth et al. 2011), economic impacts

of invasive species (Osteen and Livingston 2011; Shackleton et al. 2011; Humair et al. 2014a), cultural values and beliefs (Coates 2011; Notzke 2013; Bhattacharyya and Larson 2014) or socio-demographic variables (Norgaard 2007; Haab et al. 2010; Beardmore 2015). Despite these advancements in understanding social perceptions of invasive species, a synthesis of published literature on the issue is lacking (but see Shackleton et al. 2019b for a different approach). To this end, we need to gain a better understanding on how values and perception translate into practices and to develop methods for assessing the complex factors that influence people's perceptions (Shackleton et al. 2019a).

This study provides a systematic review of the current state of research on social perceptions of invasive species. Our definition of social perception is rooted in the literature that we reviewed; to this end, we define perception broadly as the diverse ways in which people consciously recognize invasive species. We particularly aim to identify research patterns concerning publication trends, methodological approaches, study objects, invasive species concept and factors determining the social perceptions of invasive species. A review of the perception of invasive species, and especially on the factors influencing these perceptions, can provide an important step towards transdisciplinary research and participatory decision making and thus may contribute to invasion biology as well as to sustainable conservation management and environmental policy.

Material and methods

The systematic literature review focusing on the social perceptions of invasive alien species follows the guidelines of previous systematic reviews (e.g. Abson et al. 2014; Nieto-Romero et al. 2014; Luederitz et al. 2015, 2016). For our consideration, invasive alien species are those that reached new geographic areas by human introduction and are currently leading to major impacts on the environment or society (Richardson et al. 2011). In January 2016, a keyword- based search was conducted using the Scopus database (https://www.scopus.com/), thereby including peer-reviewed English journal articles. Peer-reviewed literature is widely dominated by English articles and keeping the review restricted to one language also ensured comparability, especially when analyzing the use of terminology. Furthermore, the aim of our systematic review was to investigate research on the perception of invasive alien species and therefore we reviewed research articles and not grey literature. We opted for Scopus as our search engine, because the scientific literature is slightly biased towards Natural Science in ISI Web of Knowledge. Being aware of the application of different terms to describe invasive species in different scientific disciplines, the keywords were selected in order to cover a broad range of scientific concepts of invasive species. This review is about the scientific literature that designates invasive or alien species as the underlying construct. We did not exclude articles based on the invasion stage within the introduction-naturalization-invasion continuum. However, we expect articles on the perception of invasive alien species to be predominantly about invasive species based on the definition that they have self-replacing populations and produce reproductive offspring often in very large

numbers in the new environment (Richardson et al. 2011). We were especially interested in data about the perception of invasive alien species that are established and call for management action.

Thus, the four different search keyword strings were

(1) perception* AND invasive* AND species* (n = 288);
(2) perception* AND non-native* AND species* (n = 79);
(3) perception* AND alien* AND species* (n = 99) and
(4) perception* AND exotic* AND species* (n = 103).

Overall, we established an initial database of 569 records which could be reduced to 436 records by removing all duplicates. During the screening process, there were two different stages of selection (Suppl. material 1). First, records that were not peer-reviewed articles were excluded (n = 55). Second, we removed 251 articles that did not focus on the issue of social perception of invasive alien species by screening the abstracts (not related to invasive species (n = 139), not related to social perception (n = 81), no survey conducted (n = 31). For example, the publication by Rudrappa and Bais (2008) was returned by our search string; however it dealt with the perception strategies between plants which was not part of our research question. In another example, Finnoff et al. (2007) investigated the perception of control measures and not the perception of invasive alien species itself. These two publications were excluded together with 79 other publications that did not investigate how invasive alien species were perceived.

Then we conducted a full-text screening of the remaining 130 articles and excluded a further 53 articles that did not address our guiding questions and a further 9 articles that were not accessible. Finally, 77 articles were used for data extraction and analysis (Suppl. material 2). Our search was limited to the keyword perception, which we believe encompasses relevant concepts like attitude or opinion. However, thereby we also lost some amount of the literature that did not use the keyword perception. By counterchecking our search strings with the knowledge of important studies we verified that landmark papers were caught by our search string. Therefore, we believe that we have a consistent search string with a high specificity.

We applied quantitative data analysis of multiple variables around four criteria (Table 1): publication characteristics, methodological approach, study objects and invasive species concept. Then, to analyze the factors determining the social perception of invasive species, we applied qualitative content analysis by using MAXQDA – a software for qualitative and mixed methods data analysis (http://www.maxqda.com). Qualitative content analysis was guided by a grounded theory approach (Peterson et al. 2010) and entailed reading and re-reading the text for determining emerging patterns as categories of analysis (Fereday and Muir-Cochrane 2006). To this effect, we followed an inductive approach and developed the factors driving social perception from the material. During this iterative process, we derived five distinctive broad categories of influences (Table 2):

Table 1. Review criteria and variables extracted.

Criteria	Variables
Publication characteristics	
year of publication	1995–2016
disciplinary focus	Interdisciplinary[1], natural sciences, social sciences, transdisciplinary[2]
study site	name of the region
Methodological approach	
type of survey	interview, questionnaire, mixed, others[3]
type of data	qualitative, quantitative, both
Study objects	
species identification	name(s) of the examined species
taxonomic groups	mammals, birds, fish, reptiles, invertebrate insects, invertebrate non-insects, plants
species' environment	terrestrial, marine-coastal, fresh water
type of stakeholders	local public[4], decision-makers[5], scientists[6], others[7]
Invasive species concept	
definition of 'invasive species'	present, absent
terminology	invasive, alien, invasive alien[8], exotic, introduced, non-native

[1]Studies covering a social-ecological perspective including natural and social science perspective
[2]Studies involving academic researchers from several disciplines as well as non-academic participants in a joint problem framing process
[3]Includes workshops, discussions, focus-groups, case-studies, observation
[4]Includes residents, public and resource users like farmers, ranchers, foresters, fishers, anglers, hunters, retail professionals, gardeners, horticulturists
[5]Includes conservation professionals and managers, government employees and politicians
[6]Includes scientist and students
[7]Includes NGO-members, activist, tourists, journalists, web-users
[8]Includes 'alien invasive'

ecological conditions, *social conditions*, *values and beliefs*, *impacts*, and *benefits* of invasive alien species. *Ecological conditions* (EC) refer to the effect of invasive alien species' traits, abundance or spread on social perception. They were sub-coded into factors that referred to *species' traits* (EC_1) and species' *invasion status* (EC_2). *Social conditions* (SC) identify the societal framework's effects on social perceptions of invasive species, sub-coded as *socio-demographics and interests* (SC_1), *power, trust and responsibility* (SC_2), *language use and communication* (SC_3), and *knowledge and awareness* (SC_4). *Values and beliefs* (VB) label culturally and historically evolved mindsets' influences on social perceptions and were sub-coded into factors referring to *beliefs about nativeness* (VB_1), *beliefs about nature* (VB_2), *socio-cultural values* (VB_3), and *sense of place* (VB_4). *Impacts* (I) referred to the damaging potential of invasive species and were sub-coded into *ecological* (I_1), *economic* (I_2) and *socio-cultural impacts* (I_3). Finally, *benefits* (B), referring to beneficial effects of invasive species' traits and use, were sub-coded – complementary to *impacts* – into *ecological* (B_1), *economic* (B_2) and *socio-cultural* (B_3) benefits. The derived categories and factors influencing the social perception of invasive species with description and relevant examples from the corpus can be found in Table 2 and in more detail in Suppl. material 3. To determine significant differences and dependencies between all the collected variables (Table 1) and factors (Table 2), we conducted Chi-Square tests with R, a free software for statistical computing and graphics (https://www.r-project.org/).

Table 2. Categories influencing the social perception of invasive alien species with factors and relevant examples from the set of data.

Categories	Factors	Relevant examples from the set of data
Ecological conditions (EC)	Species' traits (EC_1) Invasion status (EC_2)	*Pastoralists' observations indicated that the presence of heavy and elongated thorns and its symbiotic relation with biting ants leads to the labeling of A. drepanolobium as the most invasive woody plant with no contribution to livestock feed* (Terefe et al. 2011: 1069). (EC_1)
Social conditions (SC)	Socio-demographics and interests (SC_1) Power, trust and responsibility (SC_2) Language use and communication (SC_3) Knowledge and awareness (SC_4)	*Poorer people will rely more on acacias for subsistence needs, whereas in richer economies tree use depends on specific commercial markets. The opportunities for such uses will be affected by the structure of land tenure (state-owned, community access and private farm) and by prevalent environmental discourses, policies and development levels in a particular region* (Kull et al. 2011: 825). (SC_1; SC_2)
Values and beliefs (VB)	Beliefs about nativeness (VB_1) Beliefs about nature (VB_2) Socio-cultural values (VB_3) Sense of place (VB_4)	*Conflicts over wild and free-roaming horses in the Chilcotin are a political and economic expression of the clash over deeper cultural and environmental values* (Bhattacharyya and Larson 2014: 674). (VB_2; VB_3)
Impacts (I)	Ecological impacts (I_1) Economic impacts (I_2) Socio-cultural impacts (I_3)	*Since its introduction Mimosa pigra has exerted a considerable impact on the environment, agricultural resources and people's livelihoods in densely populated regions in Cambodia, the weed invades and virtually 'locks up' productive floodplain areas, transforms riparian habitats, and – directly or indirectly – causes significant, economically relevant damages on the paddy fields* (Rijal and Cochard 2015: 10). (I_1; I_2)
Benefits (B)	Ecological benefits (B_1) Economic benefits (B_2) Socio-cultural benefits (B_3)	*The wattle is an important resource for village households; virtually all households used it as their primary heat source and for building materials. Other uses included medicine extraction and 20% of the interviewed households gained income from selling firewood* (de Neergard et al. 2005: 217). (B_2; B_3)

Results

Historical trends, disciplinary and geographical distribution of studies

While in the 1990s and early 2000s, publications analyzing the social perception of invasive species were scarce, with one publication in 1995, 1999, 2003 and 2005 respectively, there has been an acceleration of publications since 2010. Seventy-three percent of the publications included in this review were published between 2010 and 2015, with peaks in 2011 (19%) and 2014 (16%) (Fig. 1). The disciplinary focus of the research was predominantly interdisciplinary (62%), followed by a social science approach (31%) whereas the remaining disciplinary approaches were comparatively low with 4% of the studies using a transdisciplinary and 3% using a natural science approach (Fig. 2a). The research is dominated by studies conducted in North America (32%) and Europe (28%), followed by Africa (17%), Asia, Oceania (9% respectively) and South America (6%) (Fig. 2b).

Methodological approach, study objects and invasive species definitions

Methodological approach of the studies was dominated by quantitative (46%) and mixed methods (40%) whereas qualitative methods (14%) were used less frequently

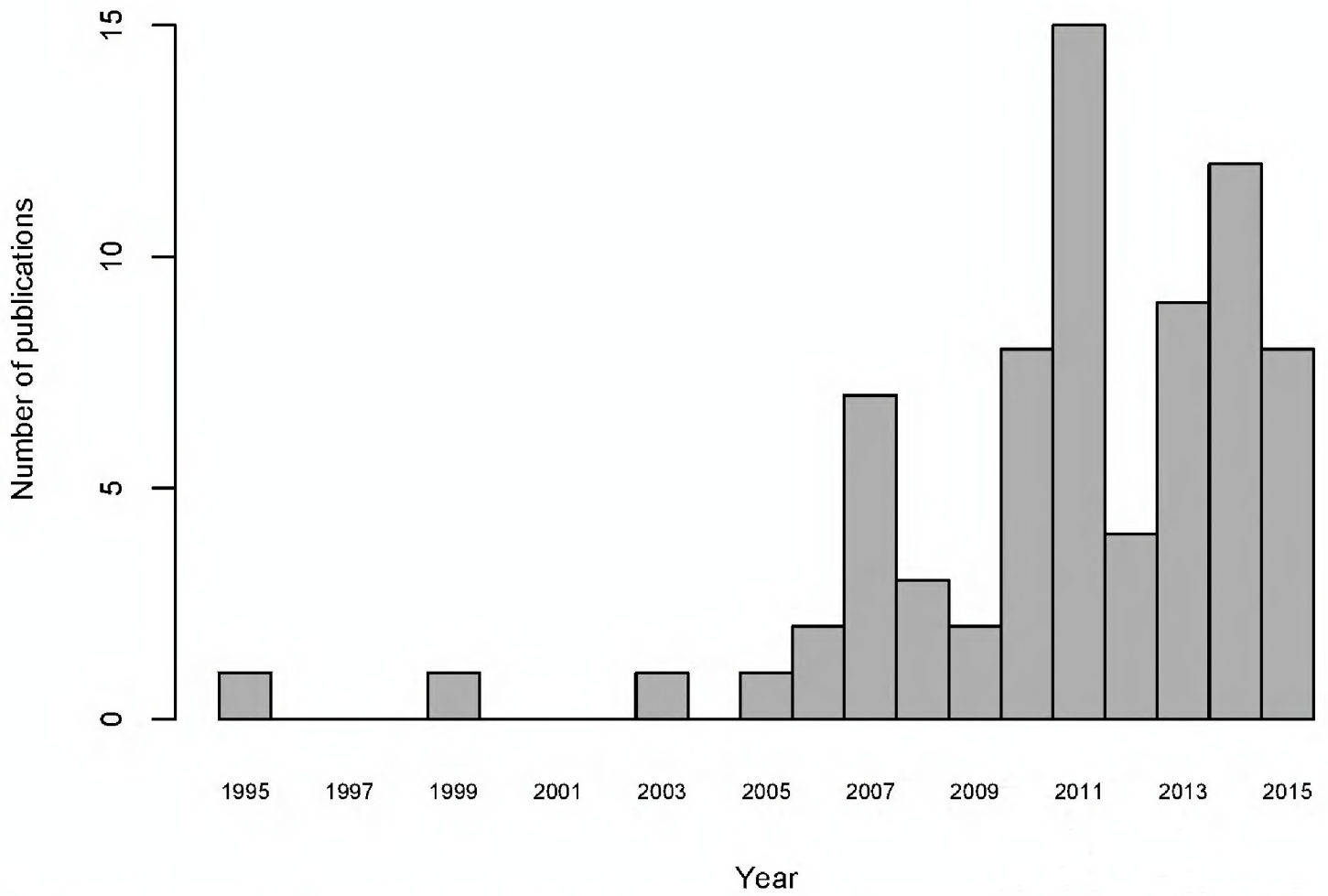

Figure 1. Number of publications included in this systematic review published per year.

(Fig. 2c). This is also reflected by the type of the surveys: the majority of studies used questionnaires (40%) or a mix of different methods (35%) followed by interviews (18%) and other approaches (7%), including workshops, discussions, focus-groups or observation (Fig. 2d). The majority of the studies focused on invasive plants (58%) and mammals (23%) (Fig. 3a) and were conducted on terrestrial environments (78%) (Fig. 3b). The complete list of study species is presented in Suppl. material 4. The majority of publications analyzed the local public's perception of invasive species (79%), followed by decision-makers (35%), scientists (23%) and 'others' (9%), including NGO-members, activists, tourists, journalists and web-users (Fig. 3c). A clear majority of 65% of the studies did not define their concept of invasive species. Use of the term 'invasive species' dominated the studies (56%), followed by 'alien species' (13%), 'non-native species' (9%), 'exotic species' and 'introduced species' (8% respectively) (Fig. 2e).

Trends concerning research characteristics

Research on the perception of invasive alien species showed clear trends, mainly referring to disciplinary bias. First, studies that were published between 2010 and 2015 were less likely to have an interdisciplinary focus than former years ($\chi^2 = 4.6$; $p < 0.05$). Second, disciplinary focus of the studies impacted geographical distribution and methodological approach of the research as well. Studies with an interdisciplinary focus were more likely to conduct their research in Africa ($\chi^2 = 10.3$; $p = 0.001$) and to use a mixed-methods ap-

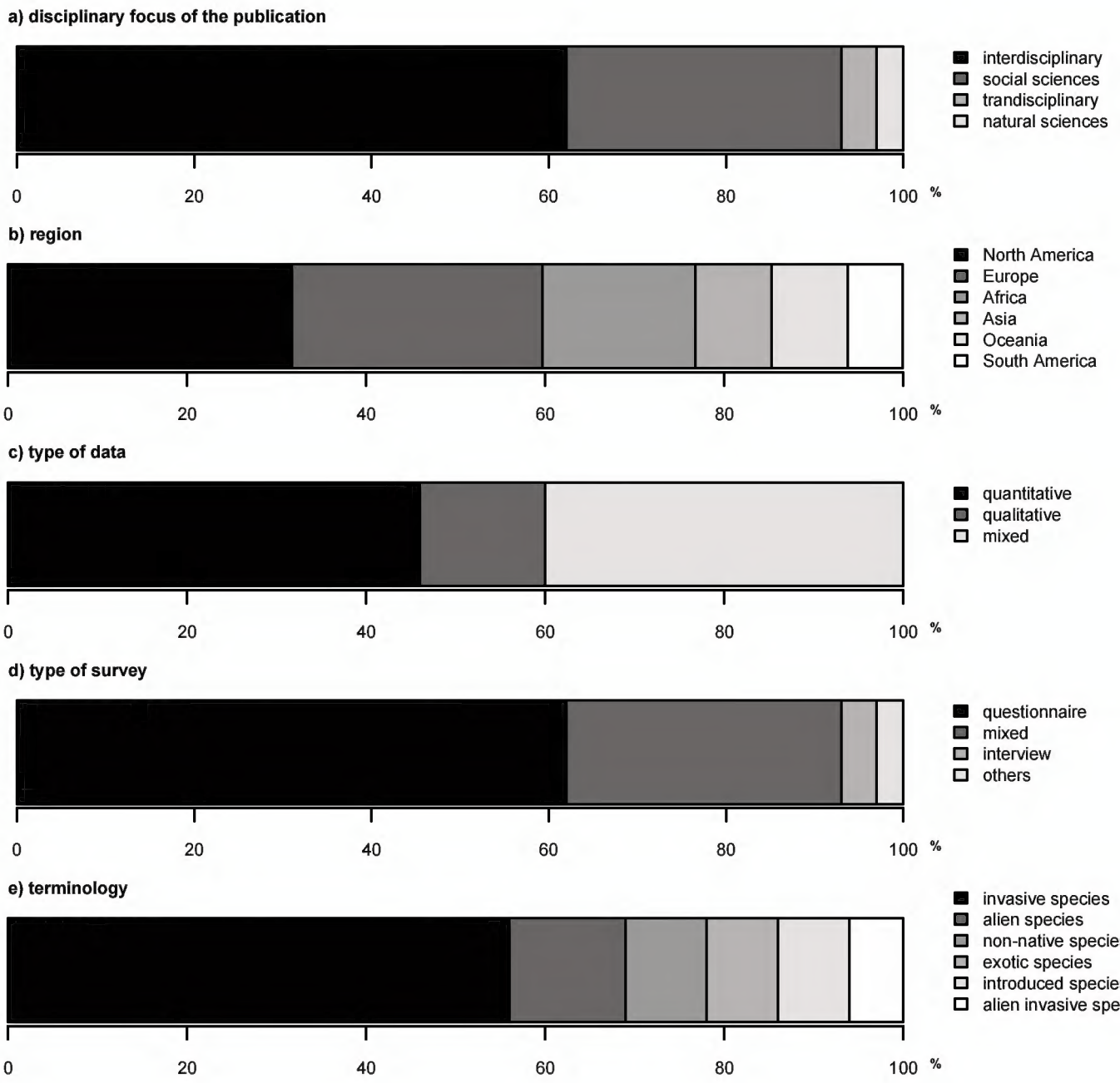

Figure 2. Percentage of studies covering publication characteristics (**a, b**), methodological approach (**c, d**) and invasive species concept (**e**).

proach ($\chi^2 = 4.0$; $p < 0.05$), whereas studies with a social science focus were more likely to conduct their research in North America ($\chi^2 = 6$; $p < 0.05$). Third, the disciplinary focus of the research significantly influenced the approach concerning definition and terminology of invasive species. Studies with a social science focus were more likely to define their concepts of invasive species ($\chi^2 = 6.9$; $p < 0.01$) and to use the term 'non-native' to describe invasive species ($\chi^2 = 5.1$; $p < 0.05$). In contrast, studies with an interdisciplinary focus were less likely to give a definition of their concept of invasive species ($\chi^2 = 6.9$; $p < 0.01$) and to use the term 'alien invasive' to describe invasive species ($\chi^2 = 6.9$; $p < 0.01$).

Factors determining the social perception of invasive species

The publications analyzed in this study referred differentially to factors influencing the social perception of invasive species. *Social conditions* (SC) were mentioned most

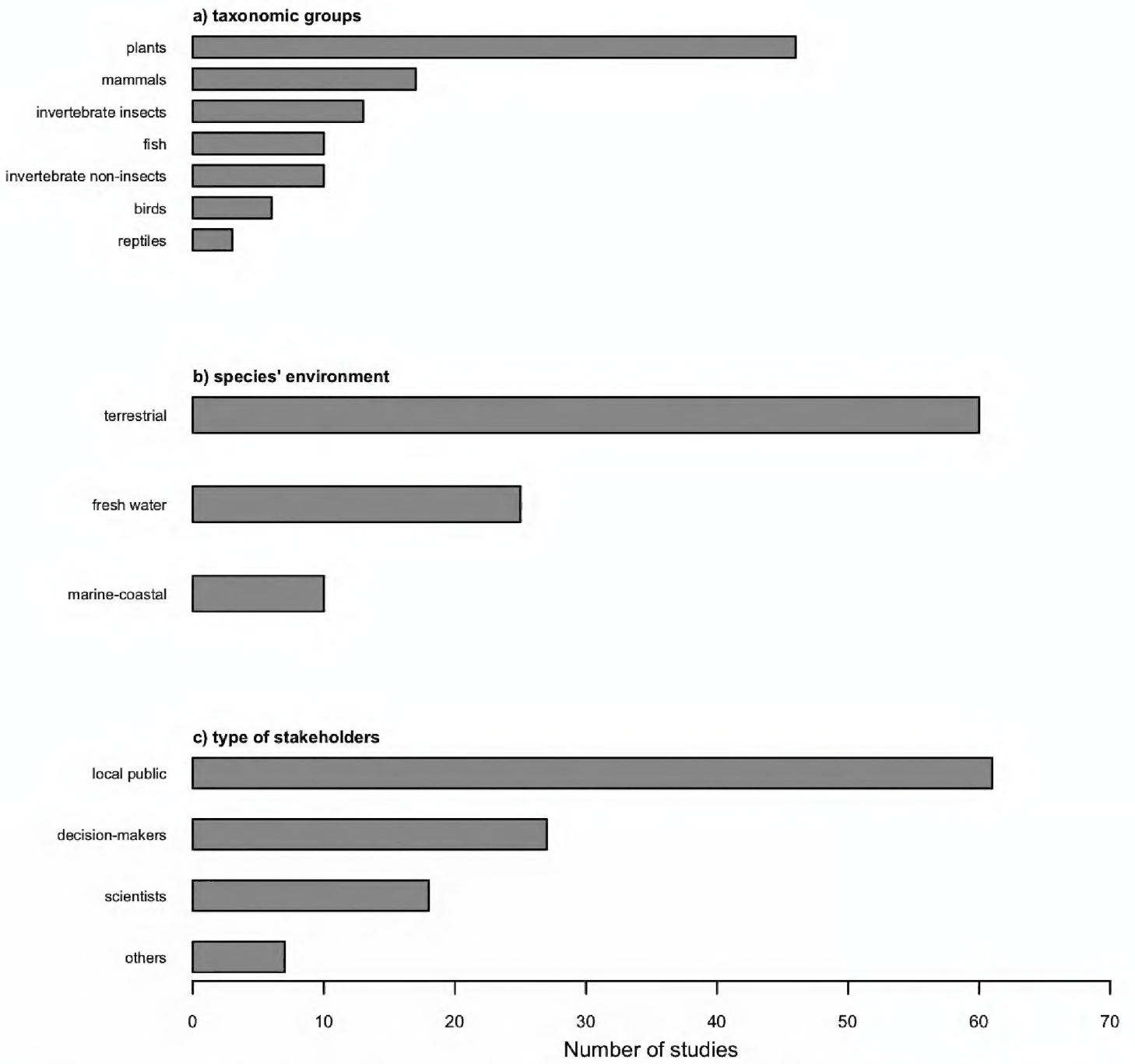

Figure 3. Study objects distinguished by **a** taxonomic group **b** species' environment and **c** type of stakeholders.

frequently by 75 out of 77 publications, followed by *impacts* (64 publications), *values and beliefs* (61 publications), and *benefits* (50 publications). *Ecological conditions* (EC) were least often determined as only 42 out of 77 publications mentioned EC as having an influence on the social perception of invasive species (Fig. 4). Factors of *social conditions* (SC) had a wide spectrum from *knowledge and awareness* (SC_4) being mentioned most often by 83% of publications, to *language use and communication* (SC_3) being mentioned least often by only 36% of publications. In contrast, the distinct factors of *values and beliefs* (VB) were quite equally distributed (Fig. 4). Notably, impacts (I) and benefits displayed a reverse distribution as 77% of the studies mentioned *ecological impacts* (I_1), followed by 56% of the studies mentioning *economic impacts* (I_2) and 48% of the studies mentioning *socio-cultural impacts* (I_3) whereas *socio-cultural benefits* (B_3) were mentioned in 57% of publications, followed by *economic* benefits (B_2) mentioned in 55% and *ecological benefits* (B_1) mentioned in 35% of publications (Fig. 4).

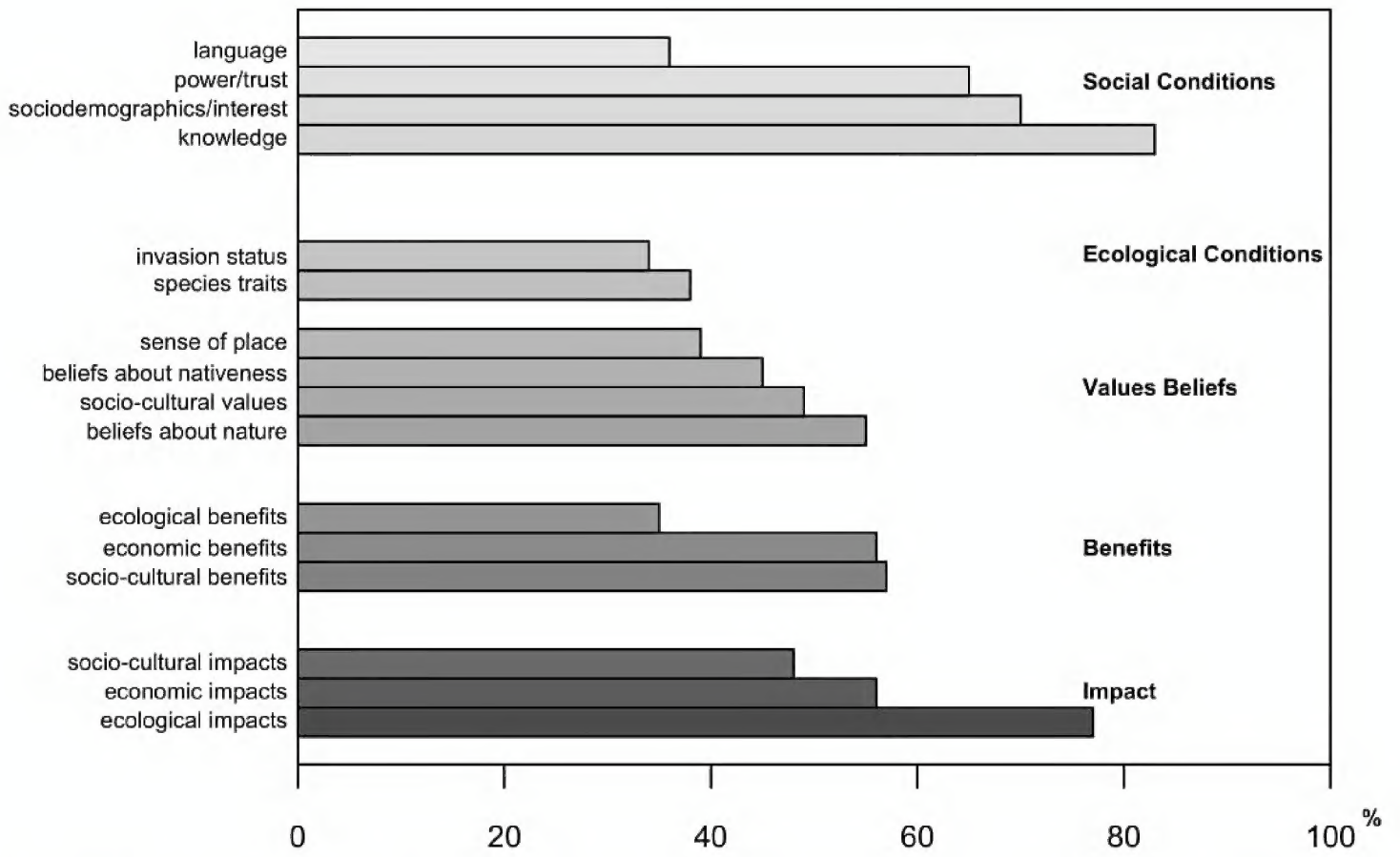

Figure 4. Factors determining the social perception of invasive species identified by the studies in percentage, distinguished by the five main categories: social conditions N = 75, ecological conditions N = 42, values and beliefs N = 61, benefits N = 50 and impact N = 64.

Dependencies of factors determining the perception of invasive species

When testing for dependencies between variables extracted from the papers (Table 1) and factors determining the perception of invasive species (Table 2), we mainly identified significant relations for *benefits* (B) and *values and beliefs* (VB).

In contrast to *impacts* (I), *benefits* (B) showed more diverse and significant relations to research characteristics. First, we found spatial differences influencing the identification of benefits of invasive species, with studies conducted in Africa being more likely to identify *ecological benefits* ($B_{1;}\chi^2 = 4.1$; $p < 0.05$) whereas studies in Europe were less likely to identify *ecological* ($B_{1;}\chi^2 = 5.3$; $p < 0.05$) and *socio-cultural benefits* ($B_{3;}\chi^2 = 4.4$; $p < 0.05$) as factors determining the social perception of invasive species. Second, results indicate a methodological bias in determining *benefits* (B). Studies using quantitative methods were less likely to identify *ecological* ($B_{1;}\chi^2 = 7.2$; $p < 0.01$), *economic* ($B_{2;}\chi^2 = 7.8$; $p < 0.001$) and *socio-cultural benefits* ($B_{3;}\chi^2 = 4.3$; $p < 0.05$) as factors determining the social perceptions of invasive species. Third, terminology to describe invasive species also determined the identification of *benefits* (B). Notably, studies that used the term 'exotic' to describe invasive species had a focus on *benefits* (B) as they were more likely to identify *ecological* ($B_{1;}\chi^2 = 5.1$; $p < 0.05$) and *economic benefits* ($B_{2;}\chi^2 = 6.4$; $p < 0.05$). Finally, study objects significantly influenced the focus on *benefits* (B), as studies that analyzed the perception of invasive invertebrate insects were less likely to identify *socio-cultural benefits* ($B_{3;}\chi^2 = 5.8$; $p < 0.05$) influencing social perceptions. Dif-

ferences in species' environments also influenced the perception of invasive species. For example, studies analyzing the social perception of invasive species in marine-coastal environments were less likely to identify *ecological benefits* ($B_{1;}\chi^2 = 6.1$; $p < 0.05$) as determining perception.

Furthermore, results indicate that terminology is characterized by a focus on *values and beliefs* (VB). Studies that used the term 'introduced' to describe invasive species were more likely to identify *socio-cultural values* ($VB_{3;}\chi^2 = 5.4$; $p < 0.05$) as well as *sense of place* ($VB_{4;}\chi^2 = 5.1$; $p < 0.05$). In contrast, studies that used the term 'non-native' to describe invasive species were more likely to examine *beliefs about nature* ($VB_{2;}\chi^2 = 4.6$; $p < 0.05$), *socio-cultural values* ($VB_{3;}\chi^2 = 8.6$; $p < 0.01$) and *beliefs about nativeness* ($VB_{1;}\chi^2 = 11.7$; $p = 0.001$) as factors influencing the social perception of invasive species.

Finally, results also indicate that there is a distinction in the perception of invasive species by stakeholders. Whereas the local public were more likely to focus on *socio-cultural benefits* ($B_{3;}\chi^2 = 4.3$; $p < 0.05$), academics attached special importance to *beliefs about nativeness* ($VB_{1;}\chi^2 = 5.4$; $p < 0.05$). Studies that examined decision-makers' perception of invasive species were more likely to identify *socio-demographics and interests* ($SC_{1;}\chi^2 = 7.7$; $p < 0.01$), *ecological impacts* ($I_{1;}\chi^2 = 6.8$; $p < 0.01$) and *sense of place* ($VB_{4;}\chi^2 = 7.0$; $p < 0.01$) as determining their view.

Discussion

Despite the entanglement of humans and invasive species and the essential role of perception in the management of invasive species, our study shows that research on social perceptions of invasive species is still in its infancy. For example, whereas Lowry et al. (2012) identified almost 300 publications per year investigating biological invasions in general in 2009 and 2010 respectively, our review focusing on social perceptions of invasive species identified only 2 publications from 2009 and 8 publications from 2010. However, more recently, researchers increasingly called for studies on the entanglement of humans with invasive alien species in order to move managing invasions forward (Shackleton et al. 2019a). Our findings complement a framework published in a special issue on the human and social dimension of invasion science which is based on six key factors that influence people's perception of invasive alien species developed during an interdisciplinary expert workshop (Shackleton et al. 2019b). Overall, our five main categories drawn from 20 years of publications correspond to the key factors developed during the expert workshop. Their key factor "attributes of individuals perceiving the invasive alien species" is reflected in our main categories *values and beliefs* (VB) and *social conditions* (SC). These factors describe the demography, values and knowledge system of the individual person. Shackleton et al. (2019b), on the other hand, summarize all attributes within the key factor "Individual(s)", based on the literature we differentiated between *values and belief* (VB) that describe beliefs about nativeness, nature, aesthetic values and sense of place and *social conditions* (SC) that describe demographics, interests, language use and communication, knowledge and awareness as

well as trust or distrust in governmental and decision-making structures. Overall, our review focused on research about the individual's perception of invasive alien species, which is reflected in the individual perspective of our categories, while Shackleton et al. (2019b) nested their key factors within a landscape, socio-cultural and institutional context. The personal perspective of trust or distrust in governmental and decision-making structures is incorporated in the framework's "Institutional, governance and policy context" which represents more formalised and larger scale structural socio-cultural factors. However, as a starting point, both approaches confront the individuals' with the species' attributes. Species' attributes are defined by species traits and invasion status and are labelled here *ecological conditions* (EC). Our results indicate that *social conditions* have been dominating social perceptions of invasive species whereas *ecological conditions* were less relevant (Fig. 4). Following the attributes of people and invasive alien species, the effects of invasive alien species are the third cornerstone in both studies. Matching the classification made by Shackleton et al. (2019b), our review confirmed the differentiation of ecological, social and economic effects of invasive alien species; however, we further distinguished between *impacts* (I) and *benefits* (B). The main difference between our categories and the Shackleton et al. (2019b) framework is that while we extracted some information on ecosystem type during the review process (Table 1) the landscape context is not part of our main categories driving the perception of invasive alien species. We did not include land tenure or land use as review categories, since these factors were not sufficiently abundant during the coding process.

One of the challenges to conduct research on social perceptions of invasive species is the need for inter- and transdisciplinary approaches. Our study shows that the interdisciplinary perspective is dominating, yet it shows decreasing trends with a concurrent increase of social sciences whereas transdisciplinary perspectives are still underrepresented. These findings are in line with Vaz et al. (2017a) who have shown that interdisciplinarity in invasion science is mostly remaining within the natural sciences. Thus, they plea for reframing biological invasions as a social-ecological research field, so fostering collaboration between science, governance and society.

Moreover, our findings reveal that research on social perceptions of invasive species comprises geographical, methodological, and taxonomic biases. First, most research has been conducted in North America and Europe (Fig. 2b). Similar results have been found previously regarding research on invasive species. For example, Pyšek et al. (2008) indicated that more than half of the studies on invasive species were conducted in North America. Similarly, Kenis et al. (2009) revealed that two thirds of studies on invasive insects are conducted in North America. This geographical bias can be explained by historical, societal, political and economic differences between Global South and Global North (Nuñez and Pauchard 2010). Second, our results indicate that there is a methodological bias in research on the social perception of invasive species (Fig. 2a). Publications are dominated by the use of quantitative and mixed methods. However, our results show that studies using quantitative methods were significantly less likely to identify benefits of invasive species. The disproportionate use of quantitative methods in research on social perceptions of invasive species may lead to

positive bias towards impacts rather than benefits. However, without the understanding of perceived ecological, economic and/or socio-cultural benefits, researchers and managers lack the socio-cultural context in which these species are embedded. The inclusion of local stakeholders' perceptions into invasive species research and management may lead to a more balanced and thus more representative view on invasive species impacts and benefits. Our findings are in line with previous systematic reviews that showed that research in different fields of invasion biology is biased, e.g. towards methods and study regions (Dana et al. 2014; Stricker et al. 2015). Third, our findings confirmed the general taxonomic bias that more studies are conducted on invasive plants than on any other taxonomic group (Pyšek et al. 2008). However, in contrast to Pyšek et al. (2008) who found that invertebrates were also abundantly studied, we found that mammals are the second largest group in the research focus (Fig. 3a). This is in accordance with Fleming and Bateman (2016) who showed that species that are particularly charismatic, large, attractive or economically valuable are more likely to be studied by invasion biologists. Our finding that invasive invertebrate studies were less likely to identify *socio-cultural benefits* of invasive species results from the focus of the reviewed literature that was either on invasive insects as vector of diseases (e.g. Abramides et al. 2013), pest species (e.g. Mackenzie et al. 2010), or species that were introduced as plaque control but became invasive (e.g. Otieno et al. 2013).

In addition, our results indicate that social conditions have dominated social perceptions of invasive species whereas ecological conditions were less relevant (Fig. 4). Furthermore, our results show differences in the social perceptions of invasive species concerning different stakeholder groups. Whereas scientists focused on invasive species' origin, decision-makers were more attached to ecological impacts and sense of place. This follows the results from Boonman-Berson et al. (2014) revealing that invasiveness is constructed differently in science and policy. Notably, decision-makers seem to form an exposed view on invasive species. Since early prevention of biological invasions is most effective compared to cost-intensive control or eradication programs, decision-makers are encouraged to implement management measures at a premature stage of invasion. They are under pressure to provide an urgent response to emerging biological invasions with only limited funding and high uncertainties (Larson et al. 2011; Liu et al. 2011; Sims et al. 2016). As scientists and conservation managers hold different priorities, motivations and approaches to engage with invasive species, communication barriers and conflicts can occur (Shaw et al. 2010). Therefore, research on invasive species is urged to integrate decision-makers' perspectives into transdisciplinary research processes, in which knowledge is co-produced by different stakeholders. Vaz et al. (2017b), for example, propose a framework for integrating ecosystem services and disservices into human valuation of plant invasions, fostering a social-ecological management of invasive species. In fact, the inclusion of different stakeholders' perspectives in the research of social perceptions of invasive species is one of the major gaps that can jeopardize the implementation of management programs aiming at resolving social conflicts associated with invasive species. Recent accounts emphasized that the problem of invasive species can also be a mutual learning process (Bryce et al.

2011; Gaertner et al. 2016), underlining the importance of including diverse stakeholders when considering management options (Novoa et al. 2018).

In particular, there is scarce research focusing on perspectives of marginalized groups. For example, Bhattacharyya and Larson (2014) criticize the lack of indigenous perspectives on invasive species in science as well as in decision-making processes. Robbins (2004), for example, addresses classed and gendered aspects of the phenomenon of invasive species. Carruthers et al. (2011) emphasize that since power transforms dominant interests of stakeholders into management decisions, power relations are strongly influencing the perception of invasive species. Thus, further research should focus on the transdisciplinary integration of balanced perspectives into invasive species management and research and conservation management should engage with power relations among stakeholders.

Our research identified an apparent lack of consensus in definition and terminology of invasive species, which is in line with an ongoing debate in invasion biology and beyond (Soulé 1990; Colautti and MacIsaac 2004; Murphy et al. 2006, Humair et al. 2014b). Existing definitions of 'biological invasions' and 'invasive species' have been critically scrutinized. Origin, behavior and impacts are identified as the main criteria defining invasive species but are criticized for being ambiguous and remaining subjective to a certain degree (Boonman-Berson et al. 2014). Whereas the terminology to describe invasive species is inconsistent and value-laden, terms like 'invasive', 'non-native', 'exotic' or 'introduced' are often used synonymously and without clear definition (Richardson et al. 2000; Bowker 2014; Parejo et al. 2015). Our results indicate that the use of different terms reflects a particular focus on different aspects of invasive species research and perception. Here, we cannot be certain how the use of different terminology by researchers already determines the outcome of species perception. For example, when the term 'exotic' was used in the research, studies focused on the benefits of invasive alien species. This is in accordance with Hall (2003) emphasizing that 'exotics' historically have been associated with providing human benefits. Ideologically motivated terminology in invasion biology is criticized massively (Warren 2007). With our present study we therefore support efforts that are undertaken to redefine the concepts of invasive species and to develop a clear common and neutral terminology (Falk-Petersen et al. 2006; Young and Larson 2011).

Furthermore, we could show that values and beliefs are an integral part of the research on perceptions of invasive species. The decisive influence of values and beliefs has also been confirmed for invasion biology and conservation management (Carruthers et al. 2011; Bocking 2015). Different conceptualizations of nature, culture and their relationships profoundly determine the perception of invasive species of both scientists and the public. There is a diverse typology of human values and heuristic rules available from Estévez et al. (2015), who present the different ethical underpinnings that people have regarding invasive species.

As biological invasions are associated with the loss of biodiversity and sense of place as well, it may demarcate a promising initial point for transdisciplinary research to include both social and ecological perspectives on invasive species (Bardsley and Edwards-Jones 2006; Keulartz and van der Weele 2009, Kueffer 2013, Essl et al. 2017). Instead

of blaming certain values as false and counterproductive, further research on invasive species should focus on a transdisciplinary and transparent discourse about the inherent values of invasion biology in order to foster negotiation of social-ecological concepts of invasive alien species and to develop sustainable valuation and management on biological invasions. In addition, based on our results, future research would clearly benefit from a consistent terminology and a plurality of method approaches (von Wehrden et al. 2017) in order to hold true on the promise that invasion science should not only highlight and enumerate problems but move management of invasive species on the ground forward.

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Supplementary material 1

Flow diagram of the selection process used in this systematic review

Authors: Katharina Kapitza, Heike Zimmermann, Berta Martín-López, Henrik von Wehrden

Data type: background information

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Link: https://doi.org/10.3897/neobiota.43.31619.suppl1

Supplementary material 2

Articles included in the analysis

Authors: Katharina Kapitza, Heike Zimmermann, Berta Martín-López, Henrik von Wehrden

Data type: background information

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Supplementary material 3

Factors influencing the social perception of invasive species

Authors: Katharina Kapitza, Heike Zimmermann, Berta Martín-López, Henrik von Wehrden

Data type: background information

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Supplementary material 4

Species examined in the publications analyzed in this review

Authors: Katharina Kapitza, Heike Zimmermann, Berta Martín-López, Henrik von Wehrden

Data type: background information

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